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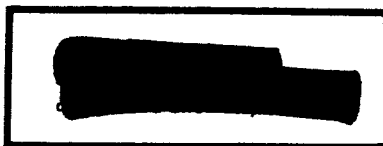
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SUBSONIC AERODYNAMIC CHARACTERISTICS OF AN
AIRPLANE CONFIGURATION UTILIZING A VARIABLE-SWEEP WING
HAVING A FREE-FLOATING APEX

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION





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SUMMARY

A low-speed wind-tunnel investigation has been made to determine the longitudinal characteristics of a variable-sweep airplane configuration which utilizes a free-floating wing apex as a means of alleviating some of the longitudinal stability and supersonic performance problems associated with variable-sweep airplanes. In this concept, the wing apex is allowed to free-float in pitch when the main wing panel is in the low-sweep positions. When the wing is swept to high angles, the wing apex is locked and becomes the apex of a conventional sweptback wing. The results of the investigation indicated that by allowing the wing apex to free-float, pitch-up could be eliminated without resorting to wing flow-control devices or special horizontal-tail locations. A large reduction in the longitudinal-stability variation with sweep angle was also obtained which would provide for improved supersonic maneuverability and reduced trim drag. It was also shown that by proper design of the wing-apex trailing edge, subsonic cruise performance penalties and sudden trim changes associated with the free-floating apex can be avoided. Tests with the apex set at various fixed incidence angles allowed for the determination of floating angles and also indicated that pitch-up can be eliminated by use of wing-apex incidence.

INTRODUCTION

Because of the desirability of developing airplanes which combine good supersonic aerodynamic characteristics, high levels of subsonic aerodynamic efficiency, and short-field take-off and landing capability, the National Aeronautics and Space Administration is investigating various methods of applying the variable-sweep wing concept. Two of the major problem areas that are being investigated are: (1) the increase in longitudinal stability with increasing sweep which can seriously limit the maneuverability and cause high trim drag and (2) the pitch-up problem. For applications where there is sufficient freedom with regard to pivot location, geometry of the fixed or apex portion of the wing, and horizontal-tail location, reasonably satisfactory solutions to these problems have been developed. (For example, see refs. 1 to 5.)

*Title, Unclassified:



However, for applications where performance, structural, or component-arrangement considerations impose such requirements as highly sweptback apexes, inboard pivot locations, and horizontal-tail locations which are undesirable with regard to stability, other solutions to these problem areas must be sought.

One approach to the problem is referred to as the "double-pivot" type of variable-sweep wing (ref. 6). In this concept, the fixed fore wing or apex portion of the wing (sometimes referred to as a "glove") is retracted into the fuselage when the main wing panel is in the low-sweep position. Retracting the apex portion of the wing into the fuselage eliminates undesirable contribution to pitch-up and compensates for at least a portion of the aerodynamic-center shift with sweep angle. Although this approach is fairly attractive from aerodynamic considerations, it is apt to encounter such problems as mechanical complexity, lack of sufficient stowage space, and loss of usable fuselage volume. A somewhat similar approach which might relieve at least the last two objections is referred to as the "free-floating apex" type of variable-sweep wing. In this concept, when the main wing panel is in the low-sweep positions, the apex is allowed to free-float in an attempt to eliminate its undesirable effects without retracting it within the fuselage. At some moderate or high-sweep position, the apex would be locked in place and form the apex of a conventional sweptback wing.

The purpose of the present investigation was to determine the subsonic longitudinal stability characteristics of a typical two-engine attack airplane utilizing the free-floating-apex variable-sweep-wing concept. Throughout this report, the term "apex" refers to the inboard fixed-sweep portion of variable-sweep wings which lies ahead of the sweeping panel and forms the apex or forward portion of a conventional sweptback wing when the sweeping panel is in the high-sweep position. The effects of positioning the apex at various fixed incidence angles relative to the main-wing-panel chord line were also investigated. The results of this part of the investigation, in addition to providing for the determination of the actual floating angles, may have application with regard to eliminating pitch-up for fixed-apex configurations.

SYMBOLS

Figure 1 illustrates the positive direction of forces, moment, and angles used in this investigation. Although only the data for the 25° sweep position are presented in this paper, the aerodynamic coefficients are based on the geometric characteristics of the wing in the 71.5° sweep position (see fig. 2) in order to be consistent with reference 6. The moment reference point was at a fuselage station 36.08 inches from the nose (18.7 percent \bar{c} at $\Lambda = 25^\circ$) for all configurations and sweep positions.

- A wing aspect ratio, b^2/s
b wing span, ft
 C_D drag coefficient, D/qS

C_L	lift coefficient, L/qS
C_m	pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS\bar{c}}$
c	local chord, ft
\bar{c}	mean aerodynamic chord, $\frac{\int_0^{b/2} c^2 dy}{\int_0^{b/2} c dy}$, ft
D	drag, lb
h_s	spoiler deflection, positive upward, in. (see fig. 4)
i_a	wing-apex incidence angle, positive when trailing edge is down, deg (see fig. 1)
L	lift, lb
q	free-stream dynamic pressure, $\frac{1}{2}\rho V^2$, lb/sq ft
S	wing area, sq ft
V	free-stream velocity, ft/sec
y	spanwise distance, ft
α	angle of attack, deg
α_a	wing-apex floating angle with respect to free-stream direction, deg (see fig. 1)
Λ	sweep angle of wing leading edge, deg
ρ	mass density of air, slugs/cu ft

DESCRIPTION OF MODEL

The model used is representative of a twin-engine attack airplane and a two-view drawing is presented in figure 2. In order to provide a valid comparison of the free-floating-apex concept with the double-pivot concept of reference 6, configuration IV of that study was used for the present investigation.

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The only difference between configuration IV of reference 6 and the present configuration therefore is that, rather than retracting the apex into the fuselage, it is allowed to free-float when the main wing panel is in the low-sweep position (25° sweep). Inasmuch as the configuration with the wing in the high-sweep position (71.5° sweep), is identical to configuration IV of reference 6, tests were made only with the main wing at the 25° sweep position.

Details of the free-floating apex are presented in figure 3. The apex hinge line was normal to the fuselage reference line and parallel to the wing chord plane. The hinge consisted of a steel pin with one end attached rigidly to the apex and the other supported by a bearing attached within the fuselage. This allowed the wing apex, when free floating, to rotate in the pitch plane. It will be noted that the free-floating apex had a beveled trailing edge and an adjustable spoiler control (fig. 4). These features were used only as convenient means of investigating a range of wing-apex floating angles during the tests. For a practical application of the free-floating-apex concept, the apex trailing edge would contain some type of slot to allow mating of the apex and main wing panel for the high-sweep position. In addition, some mechanical or aerodynamic method of positioning the apex properly just prior to the mating phase would be required.

TESTS AND CORRECTIONS

The investigation was made in the Langley high-speed 7- by 10-foot tunnel at a dynamic pressure of 75 lb/sq ft, corresponding to a Mach number of 0.23 and a Reynolds number per foot of approximately 1.65×10^6 . This tunnel is an atmospheric tunnel with the upper and lower walls slotted longitudinally. No corrections are necessary for jet-boundary induced upwash or blockage in the slotted test section with models of the size used in this investigation.

Photographs of the model mounted on the sting support in the Langley high-speed 7- by 10-foot tunnel are shown as figure 5. The model was sting mounted to reduce support interference, and the forces and moments were measured with an internal six-component strain-gage balance. The angle of attack was corrected for the deflection of the sting and balance under load, the base pressure was measured and the drag adjusted to correspond to free-stream static pressure at the base, and the internal duct drag was measured and subtracted from the total drag. No sting interference corrections have been applied to the data; however, a partial correction for sting interference is inherent in the base-pressure correction. Transition was fixed on all surfaces with a narrow strip of No. 100 carborundum grains.

PRESENTATION OF RESULTS

The basic data are presented in figures 6 to 11 and comparisons indicating some of the more pertinent results are presented in figures 12 to 16. As an aid in locating a particular data figure, the following listing is presented:

Basic data:

Effect of wing-apex spoiler deflection on aerodynamic characteristics of model with free-floating apex:	
Complete configuration	6
Horizontal tail off	7
Effect of negative wing-apex incidence angle on aerodynamic characteristics of model with fixed wing apex:	
Complete configuration	8
Horizontal tail off	9
Effect of positive wing-apex incidence angle on aerodynamic characteristics of model with fixed wing apex:	
Complete configuration	10
Horizontal tail off	11

Summary comparisons:

Comparison of pitching-moment characteristics of model with free-floating, fixed, and retracted wing apex	
Effect of angle of attack and apex spoiler deflection on wing-apex floating angles	12
Effect of free-floating wing apex on variation of lift-drag ratio with lift coefficient	13
Effect of wing-apex incidence angle on variation of pitching-moment coefficient with lift coefficient	14
Effect of wing-apex incidence angle on variation of lift-drag ratio with lift coefficient	15
Effect of wing-apex incidence angle on variation of lift-drag ratio with lift coefficient	16

The basic data obtained in this investigation, presented in graphical form in figures 6 to 11, are for the 25° sweep condition of the main wing panels since in the free-floating-apex concept the apex would be allowed to free-float only when the main wing panels are in the subsonic mode. With the wings in the high-sweep mode, the apex would be locked and form the apex of a conventional sweptback wing; the basic data for this condition are presented in figures 13 and 23 of reference 6 for subsonic and supersonic speeds, respectively.

Figure 6 presents the longitudinal aerodynamic characteristics of the complete configuration with the apex free floating for various deflections of the apex spoiler control. The apex spoiler control, details of which are shown in figure 4, was utilized to control the floating characteristics of the apex. For example, with the spoiler deflected up a sufficient amount, the apex would be expected to float at a positive angle of attack relative to the free-stream (or flight) direction and thereby provide a positive lift increment while still maintaining an essentially neutral longitudinal stability contribution to the complete configuration. The beveled trailing edge of the basic wing apex results in an effective camber which would be expected to provide some degree of positive floating angle. Therefore to assure a range of floating angles, both positive and negative, negative apex-spoiler-control deflections were tested. The data for the configuration with the horizontal tail removed are presented in figure 7.

In order to allow for the determination of the actual apex floating angles α_a , data were also obtained with the apex fixed at various incidence angles i_a . These data are presented in figures 8 to 11. The wing-apex floating angles, which are discussed subsequently, were determined by the intercept method. The intercept angle is that angle of attack for which the fixed-incidence-apex and the free-floating-apex pitching moments are equal. From the intercept angle of attack and the apex incidence, the floating angle can be obtained. In addition to the effect of apex incidence on the longitudinal aerodynamic characteristics, figure 8 also shows the effect of sealing the gap between the apex and the main wing with the apex at zero incidence. For other incidence angles, of course, the gap is always unsealed. Figures 8 and 9 present aerodynamic data for the negative wing-apex incidence range for the tail-on configuration and tail-off configuration, respectively. Figures 10 and 11 present the corresponding data for the positive wing-apex incidence range. Although the data for fixed-apex incidence angles are directly applicable for the determination of the floating angles, they also may be of interest in connection with adjustable-apex-incidence approaches to the pitch-up problems.

DISCUSSION

Characteristics With Free-Floating Apex

Longitudinal stability.- The longitudinal stability characteristics of the model with the free-floating apex are presented in figure 6 for the complete configuration and in figure 7 for the horizontal-tail-off configuration. Data are presented for various deflections of the apex spoiler control. As mentioned previously, one purpose of the apex spoiler control was to trim the apex so that it would float at a relatively constant positive angle of attack (relative to free-stream direction) and thereby provide positive lift but essentially no variation of pitching moment with angle of attack. However, the results indicate a negligible effect on lift and, for all but the configuration with $h_s = -4$ inches, a sudden trim change. In view of this result, only the data for the configuration with the spoiler deflection of -4 inches are discussed in this section.

To illustrate the possible benefits of the free-floating apex, figure 12 has been prepared. In this figure the variation of pitching-moment coefficient with lift coefficient for the 25° sweep configuration with the free-floating apex is compared with that for the fixed apex in combination with main wing panels at 25° sweep (from fig. 8) and 71.5° sweep (from fig. 13 of ref. 6). Two benefits associated with the free-floating apex are apparent from this comparison. First, by allowing the apex to free-float with the main wing panel at 25° sweep there is a sizable rearward shift of the aerodynamic center towards the aerodynamic-center position for the 71.5° sweep condition. This reduction in aerodynamic-center shift with sweep allows balancing of the airplane so that the longitudinal stability with the wings in the high-sweep position can be reduced thereby increasing the high-speed maneuverability and reducing the trim drag without encountering instability at subsonic speeds with the 25° sweep position. Also shown in figure 12, by the dashed line, are the data obtained with the main

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wing panel in the 25° sweep position but with the apex removed, as in the double-pivot concept. (See fig. 10 of ref. 6.) This comparison indicates that the free-floating apex is almost as effective in reducing the longitudinal-stability variation with sweep as is the retracting apex of the double-pivot concept.

The second benefit apparent from the comparison of figure 12 is the effectiveness of the free-floating apex in eliminating the pitch-up encountered with the fixed apex with the wing in the low-sweep condition. This effect is important in that it eliminates the need for wing flow-control devices and allows some latitude in the vertical location of the horizontal tail.

Floating angles.- The apex floating angles (relative to free-stream direction) assumed by the free-floating apex have been determined from the free-floating-apex and fixed-incidence pitching-moment data by using the intercept method described previously. These floating angles α_a are presented in figure 13 as a function of angle of attack α for the various apex spoiler settings h_s . The data indicate that at low angles of attack the large positive spoiler setting results in very large positive floating angles. However, as the angle of attack is increased there is a sudden reversal resulting in negative floating angles. Beyond the reversal points, the rate of change of floating angle with angle of attack is essentially the same for all spoiler settings and is associated with the rate of change of fuselage and wing upwash with angle of attack. The results for the configuration with $h_s = -4$ inches indicate that the sudden trim change can be avoided for any positive α by trimming the apex so that its trailing edge tends to float above the main wing leading edges throughout the operational angle-of-attack range.

Performance.- One advantage of the free-floating-apex concept is the previously mentioned increase in supersonic performance made possible through a reduction in trim drag. However, at subsonic speeds when the apex is free floating, it is rather apparent that some performance penalties could be encountered. As an indication of the subsonic cruise performance attainable with the free-floating apex, figure 14 presents the variation of the lift-drag ratio with lift coefficient for the fixed apex ($i_a = 0^\circ$) and the free-floating apex with spoiler-control deflections of 0 and -4 inches. These results are for the model as tested and have not been extrapolated to full-scale friction-drag and induced-drag conditions. The comparison indicates that with the apex spoiler deflected -4 inches (the setting which provided the most desirable longitudinal stability characteristics), the maximum lift-drag ratio for the model with the free-floating apex is somewhat lower than that for the model with the fixed apex. However, since this loss is associated with the drag of the particular spoiler control used, it is believed that the performance loss can be avoided by careful design. Evidence of this can be seen in the fact that with the spoiler control neutral there is essentially no loss in the maximum lift-drag ratio despite the fact that the apex trailing edge is rather blunt. It will also be noted that in the moderate lift-coefficient range the free-floating apex provides an improvement in drag due to lift, possibly because of an improved spanwise load distribution. However at the higher lift coefficients, where

appreciable loss in leading-edge suction is encountered on the main wing panel, the angle of attack required for a given lift coefficient becomes an important factor in the drag due to lift; therefore, the free-floating apex causes a reduction in lift-drag ratio because of the lack of apex lift. This reduction in lift-drag ratio may not be as large at full-scale Reynolds numbers because of the greater amount of suction maintained.

Effect of Fixed Apex Incidence

The effect of various incidence angles on the low-speed longitudinal aerodynamic characteristics of the model with fixed wing apex is presented in figures 8 to 11. The results indicate that improvements in the pitching-moment variation with lift or angle of attack can be achieved with either positive or negative incidence angles of the apex. For the large negative incidence angles, the improvement appears to be associated primarily with the fact that at the higher angles of attack the large negative apex incidence angles shift the apex from its high-lift-curve range to its low-lift-curve range so that the lift and pitching-moment characteristics of the complete configuration in the high angle-of-attack range approaches those obtained for the complete configuration with the free-floating apex (compare fig. 8 with fig. 6) or with the apex off (compare fig. 8 with fig. 10 of ref. 6). For the highest negative incidence angle, a rather large loss of lift and an increase in drag occur; however, fairly linear pitching-moment characteristics were also achieved with an incidence angle of -10° with only a minor loss of lift and slight increase in drag. Also of interest in figure 8 is the improvement in stability associated with opening the apex gap for the $i_a = 0^\circ$ apex condition. The favorable effect on stability of the large positive wing-apex incidence angle ($i_a = 20^\circ$) is shown in figure 10 for the complete configuration. This favorable effect may be due to stalling of the apex at the high apex angle of attack associated with the combined effect of airplane angle of attack, wing upwash, and apex incidence.

Figures 15 and 16 summarize the possible improvements attainable for the complete configuration with the negative apex incidence angles. Figure 15 shows the pitching-moment characteristics for the 0° , -10° , and -20° apex settings and illustrates that the pitch-up can be eliminated for settings slightly in excess of -10° . Figure 16 presents the lift-drag characteristics and indicates that even though the -20° setting results in a significant loss in performance the -10° deflection actually shows an increase in performance relative to the zero-incidence condition. This improvement was obtained despite the rather large base area of the apex (see figs. 4 and 5), and it would appear that by providing for closure of the wing-apex base and optimizing the gap between the apex and the main wing panel additional performance gains could be combined with the stability improvement.

CONCLUDING REMARKS

A low-speed wind-tunnel investigation has been made to determine the longitudinal characteristics of a variable-sweep airplane configuration which

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utilizes a free-floating wing apex as a means of alleviating some of the longitudinal stability and supersonic performance problems associated with variable-sweep airplanes. The results of the investigation indicated that pitch-up could be eliminated without resorting to wing flow-control devices or special horizontal-tail locations. A large reduction in the longitudinal-stability variation with sweep angle was also obtained which would provide for improved supersonic maneuverability and reduced trim drag. It was also shown that by proper design of the wing-apex trailing edge, subsonic cruise performance penalties and sudden trim changes associated with the free-floating apex can be avoided. Tests with the apex set at various fixed incidence angles allowed for the determination of floating angles and also indicated that pitch-up can be eliminated by use of wing-apex incidence.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., May 4, 1965.

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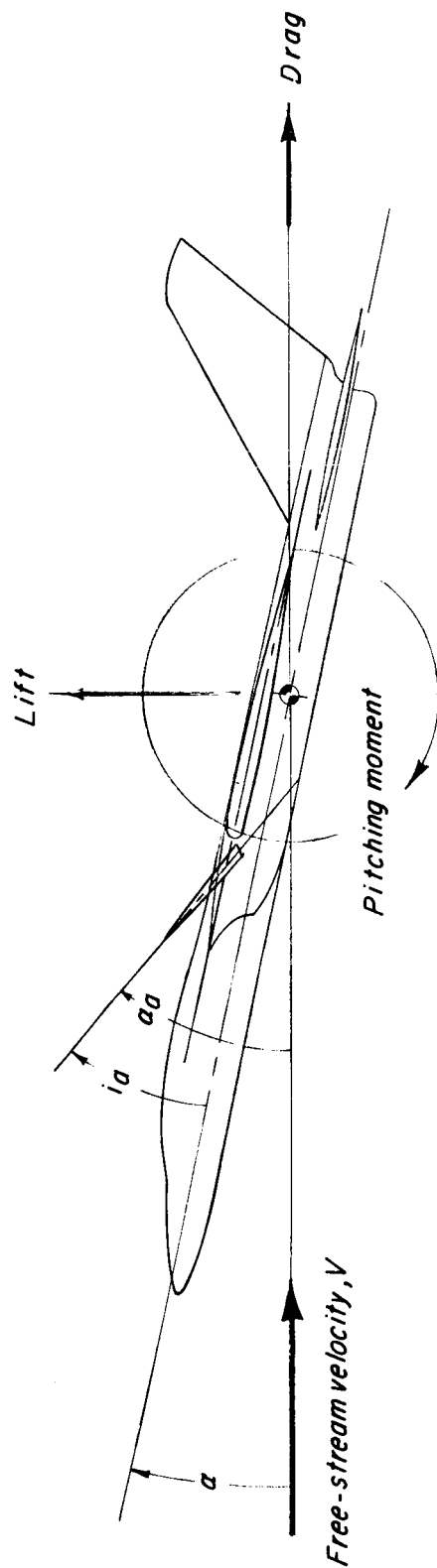


Figure 1.- Illustration showing positive direction of forces, moment, and angles.

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25.00°	2.37 ft^2	7.77	51.36	7.71
71.50°	3.54 ft^2	19.32	31.78	1.97

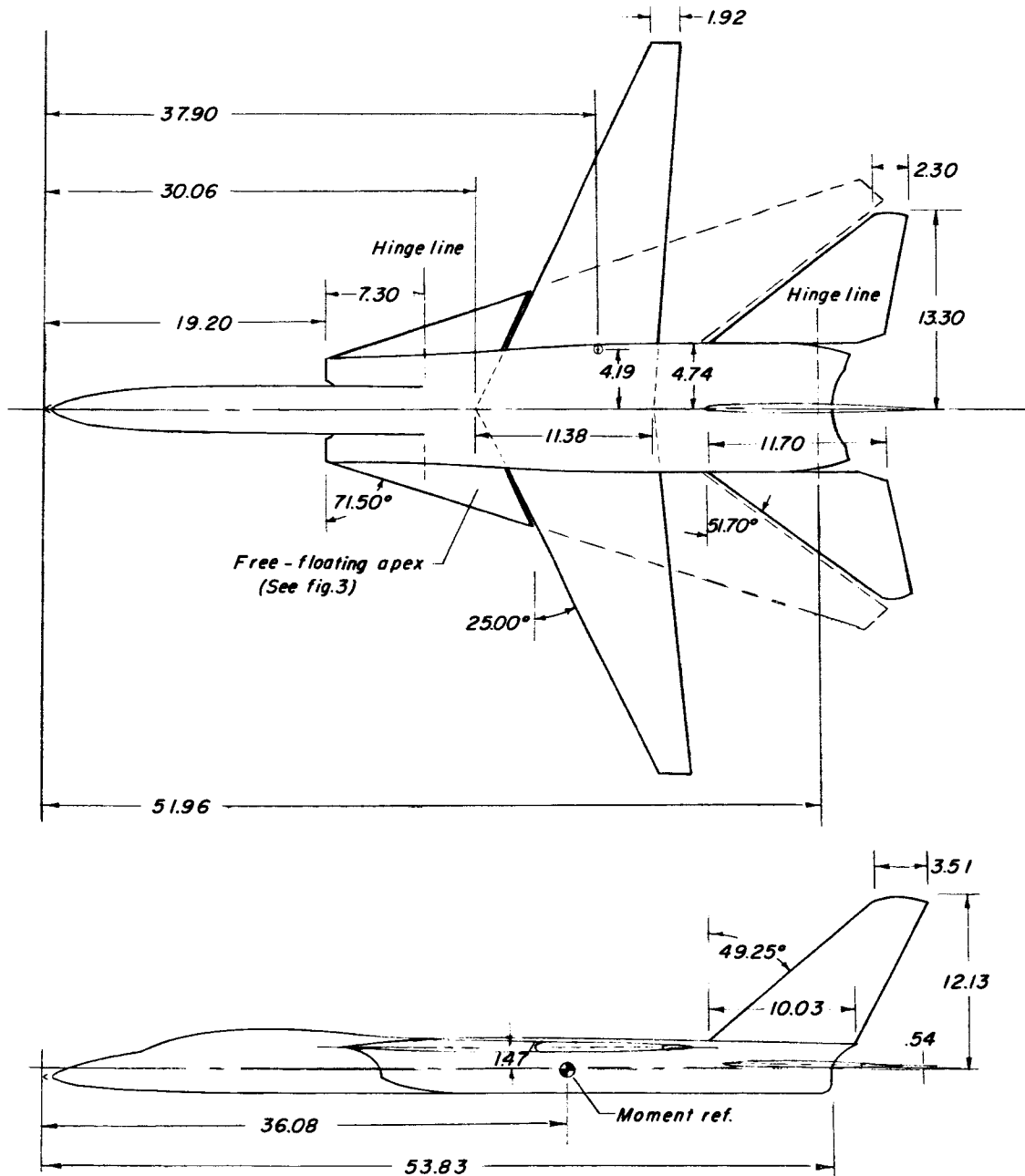
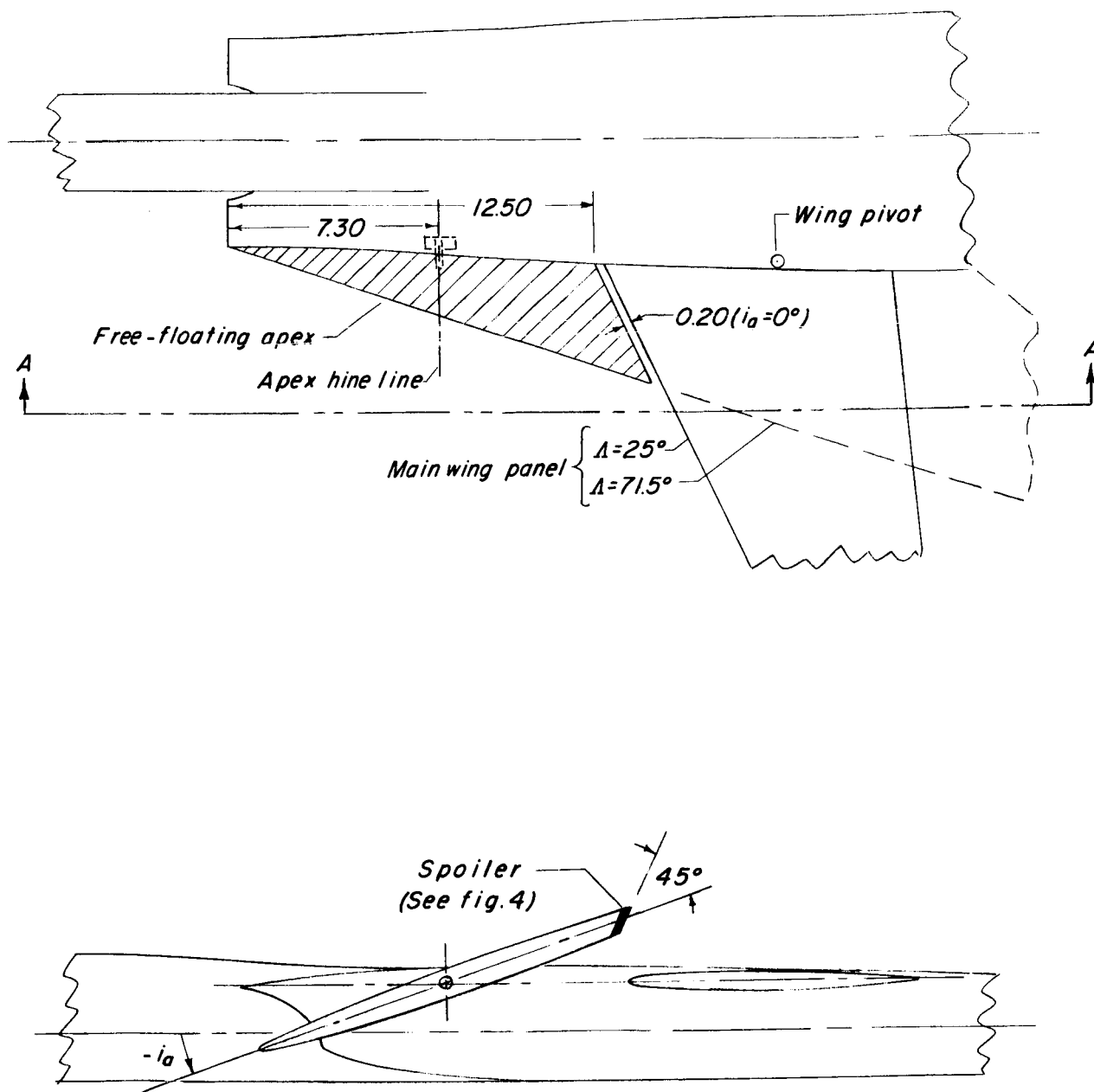


Figure 2- Two-view drawing of model as tested. All dimensions in inches unless otherwise noted.



Section A-A ($\Lambda = 25^\circ$ - apex free floating)

Figure 3.- Details of free-floating apex. All dimensions in inches.

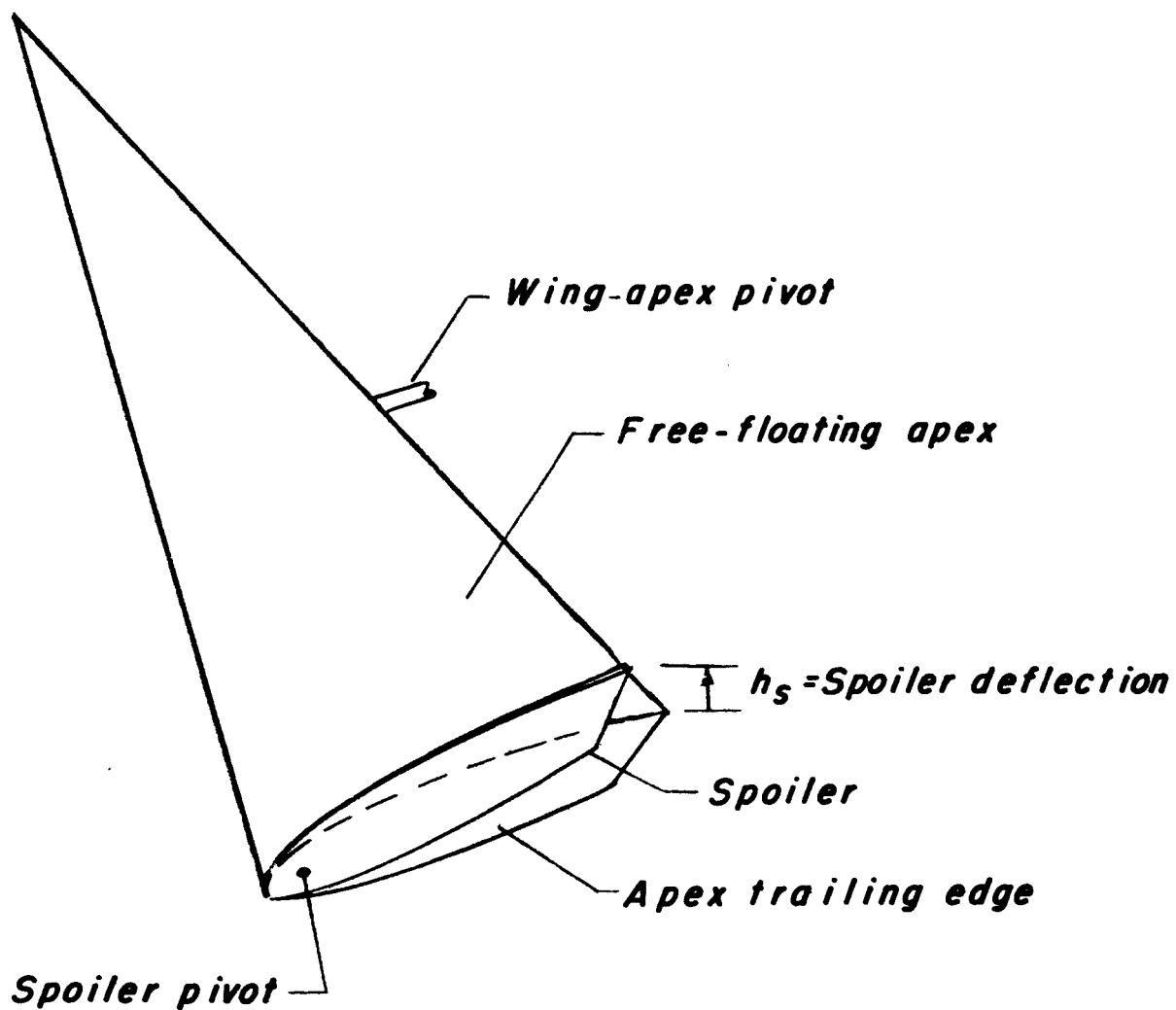


Figure 4.- Sketch showing spoiler control attached to apex trailing edge.



Figure 5.- Photographs of model in tunnel.

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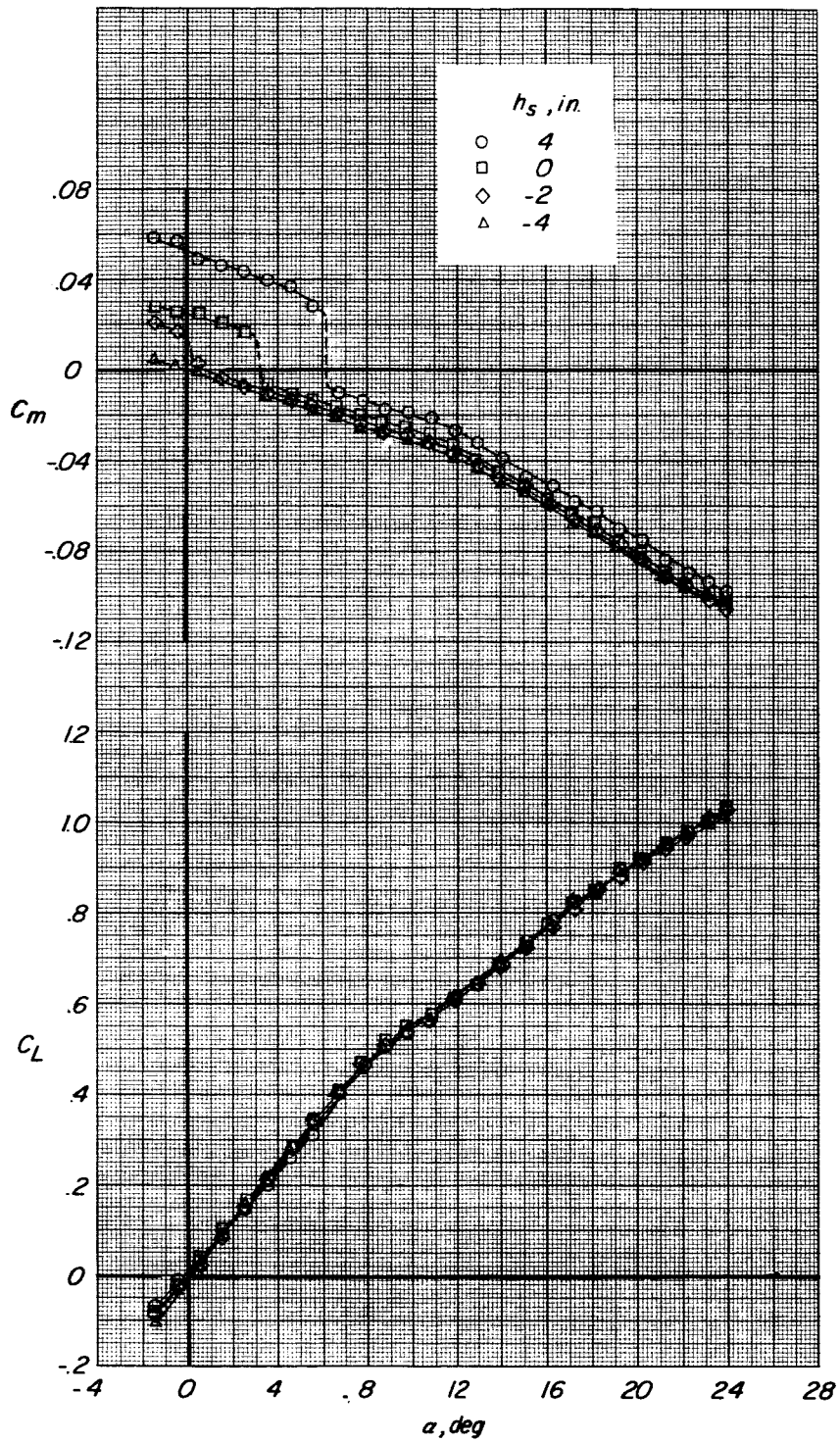


Figure 6.- Effect of wing-apex spoiler deflection on aerodynamic characteristics of model with free-floating apex. Complete configuration; $\Lambda = 25^\circ$.

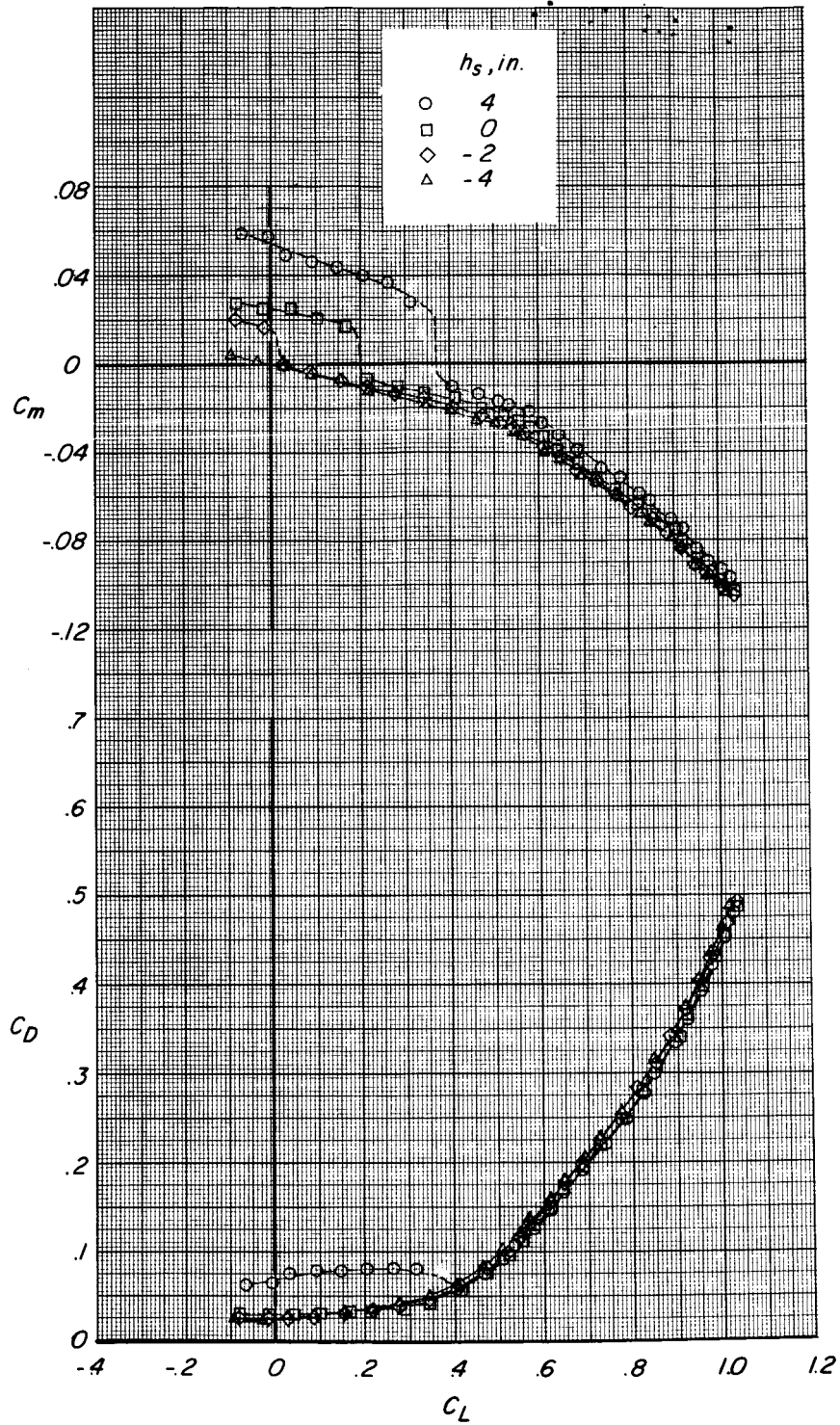


Figure 6.- Concluded.

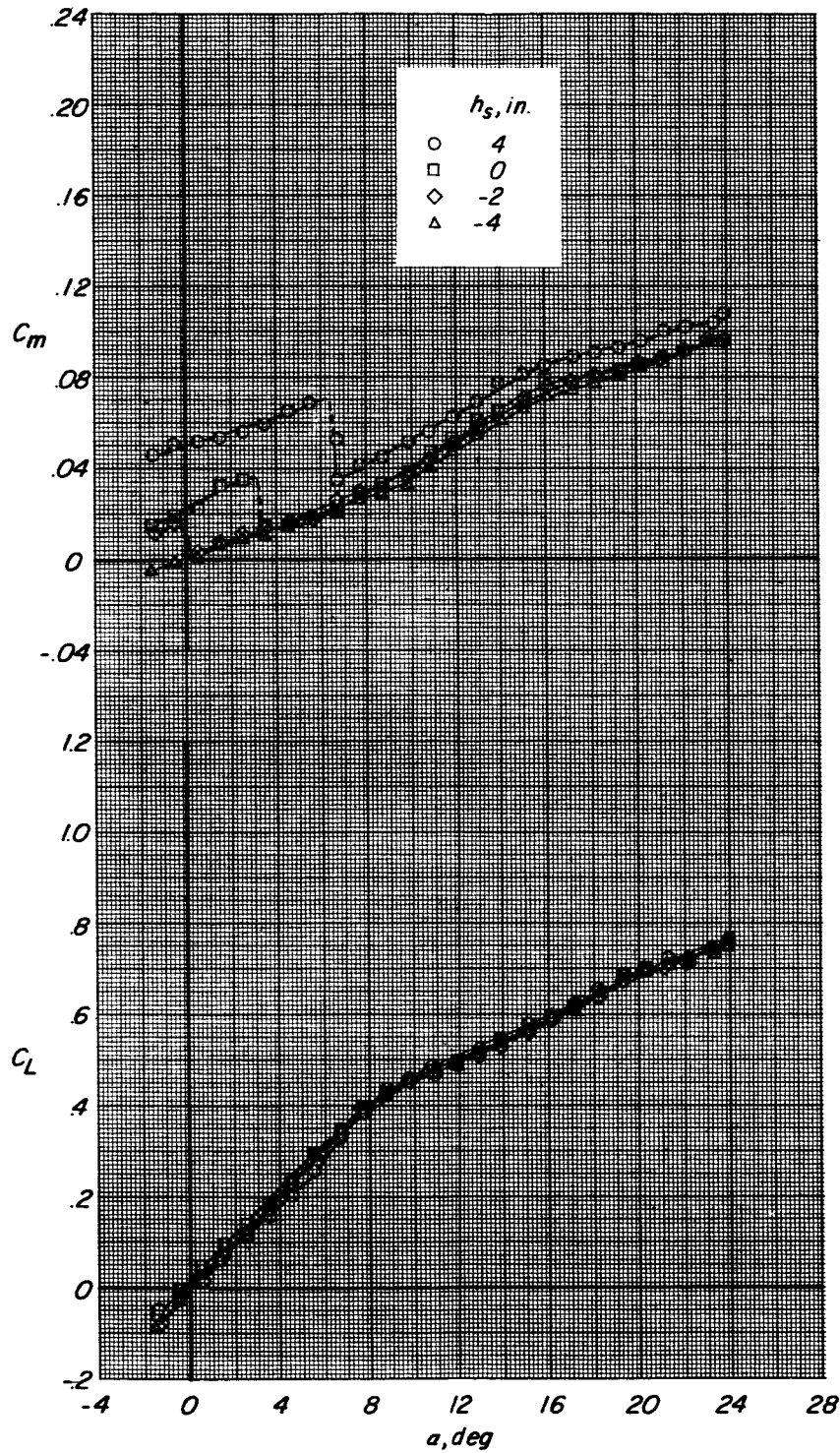


Figure 7.- Effect of wing-apex spoiler deflection on aerodynamic characteristics of model with free-floating apex. Horizontal tail off; $\Lambda = 25^\circ$.

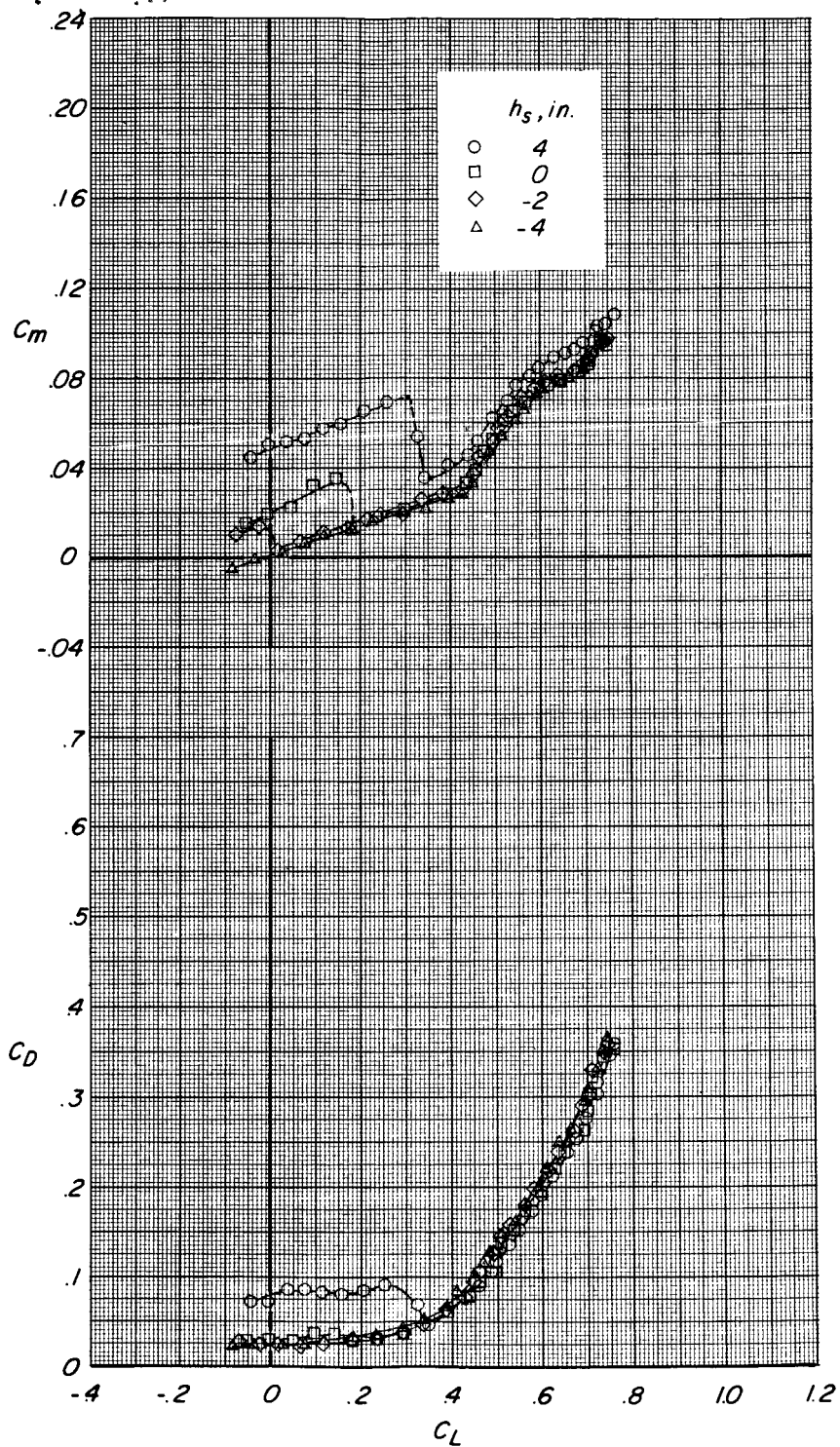


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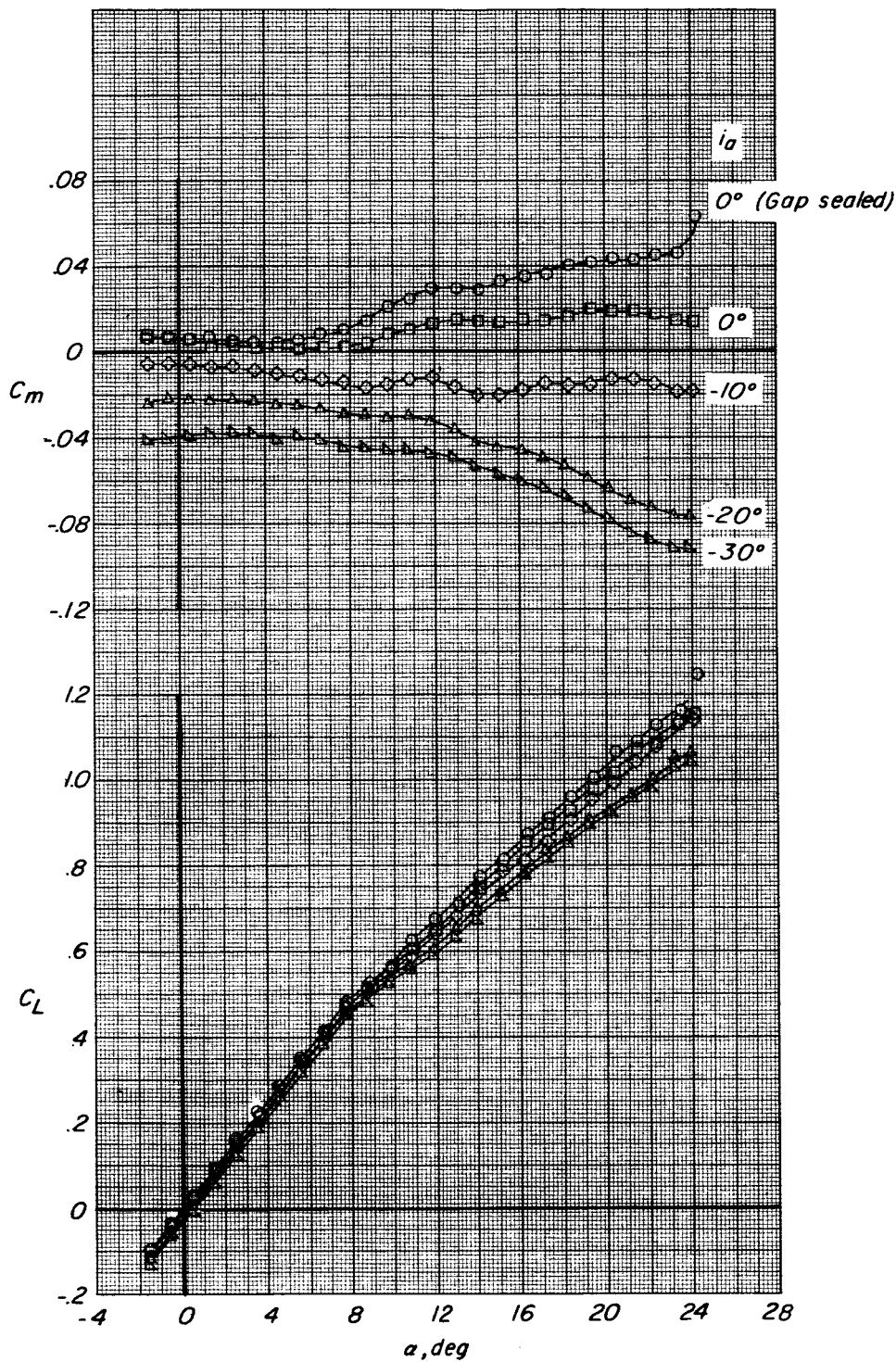


Figure 8.- Effect of negative wing-apex incidence angle on aerodynamic characteristics of model with fixed wing apex. Complete configuration; $\Lambda = 25^\circ$; $h_s = 0$.

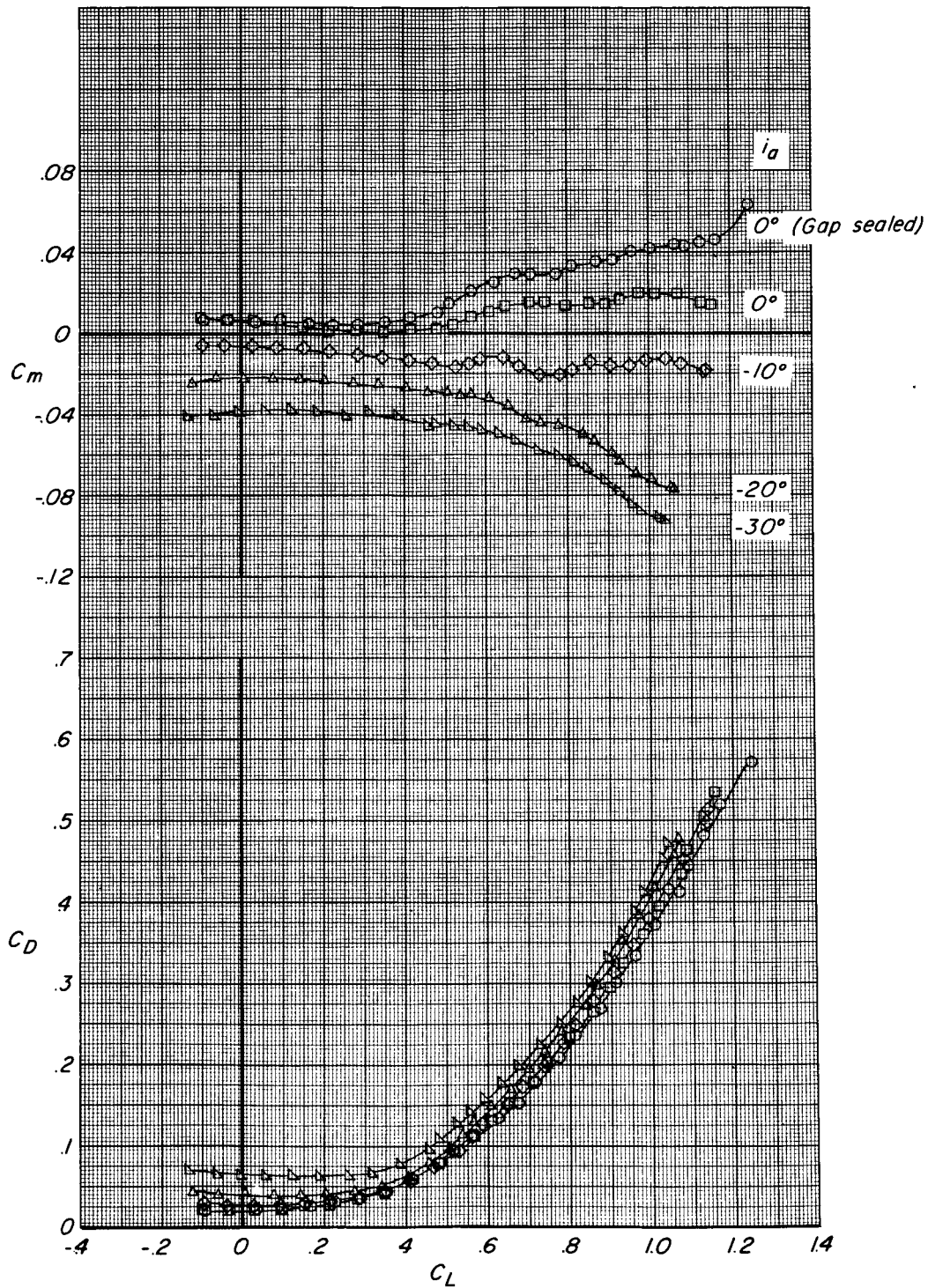


Figure 8- Concluded.

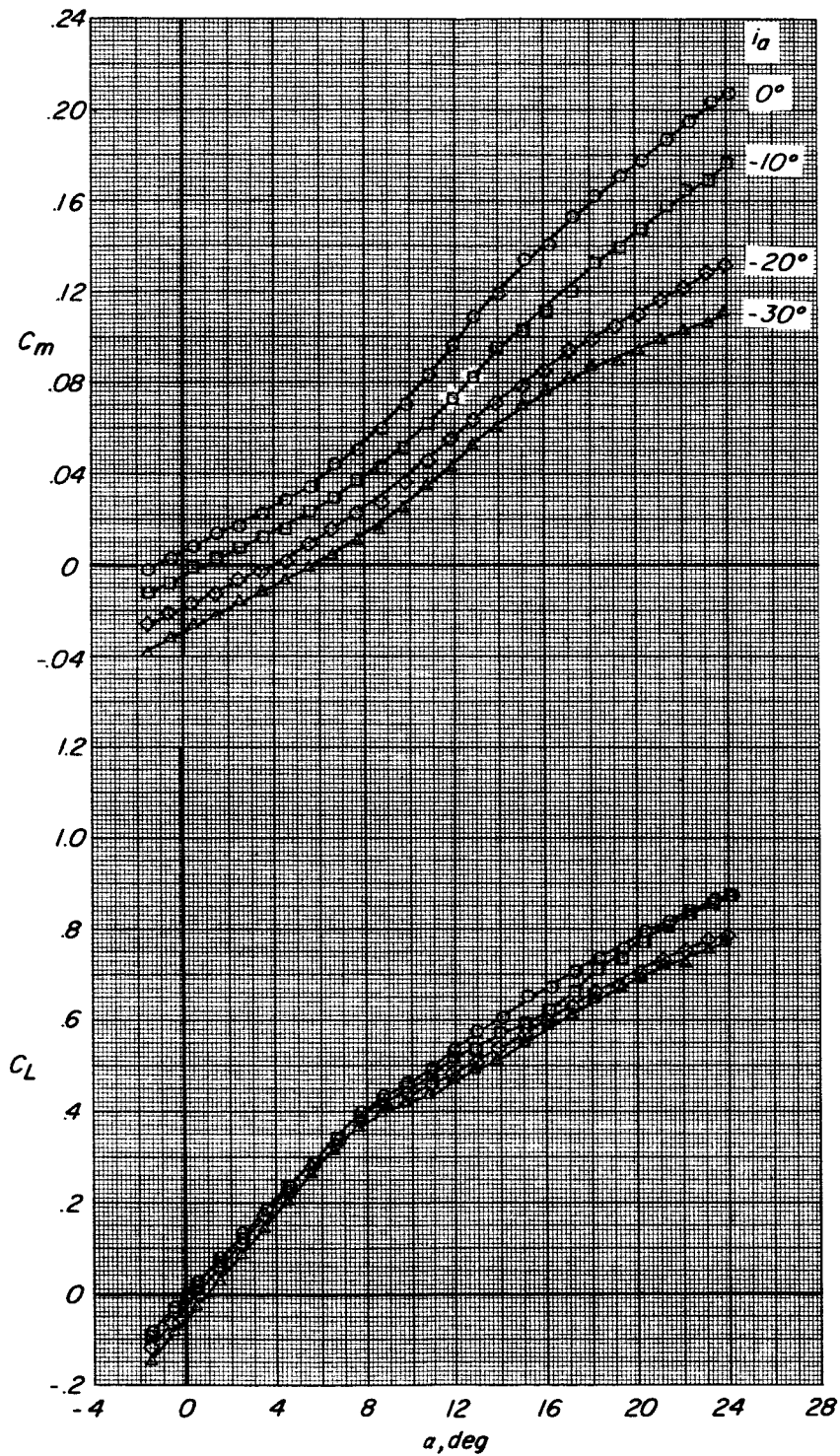


Figure 9.- Effect of negative wing-apex incidence angle on aerodynamic characteristics of model with fixed wing apex. Horizontal tail off; $\Lambda = 25^\circ$; $h_s = 0$

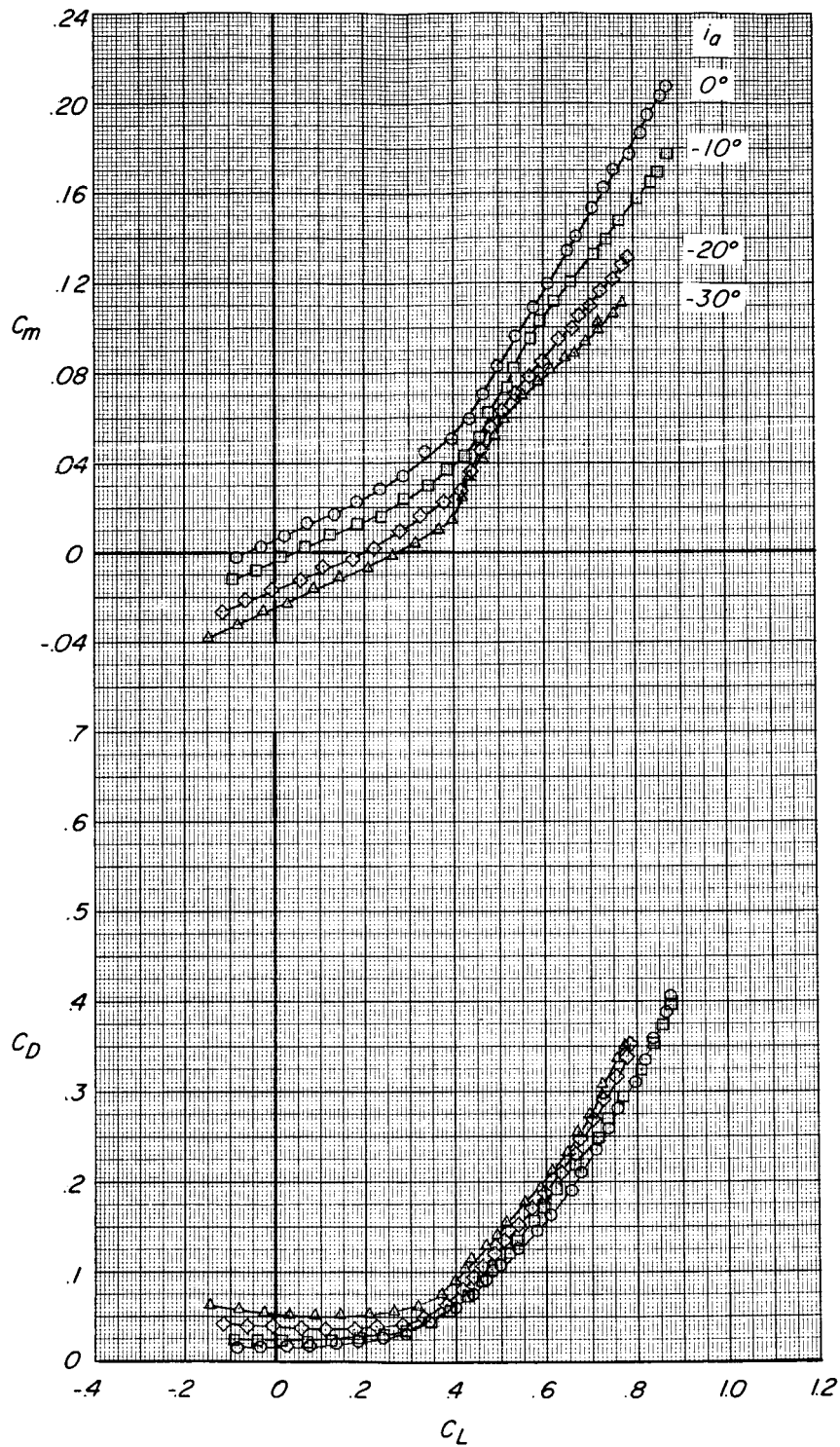


Figure 9.- Concluded.

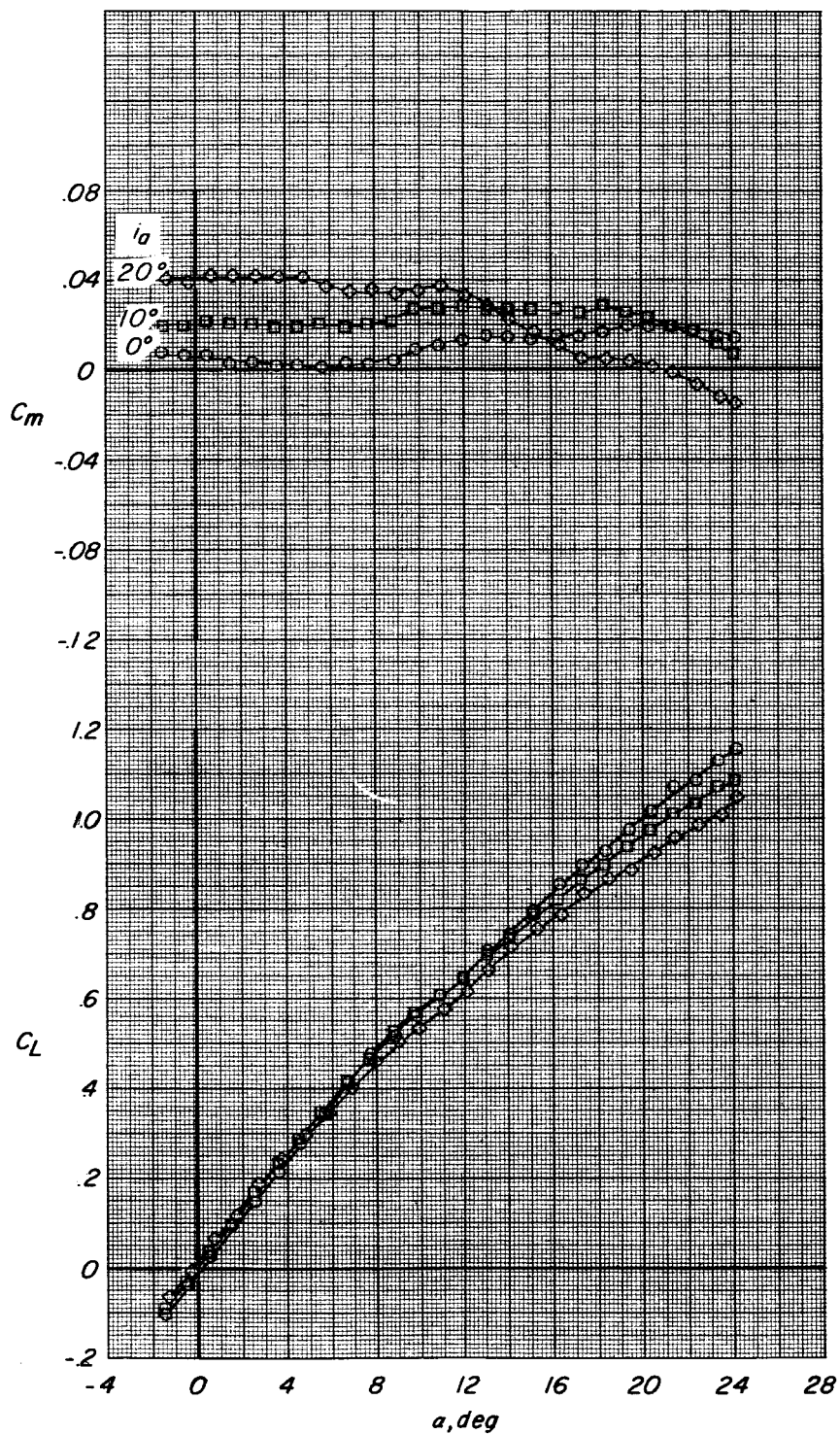


Figure 10.- Effect of positive wing-apex incidence angle on aerodynamic characteristics of model with fixed wing apex. Complete configuration; $\Lambda = 25^\circ$; $h_s = 0$.

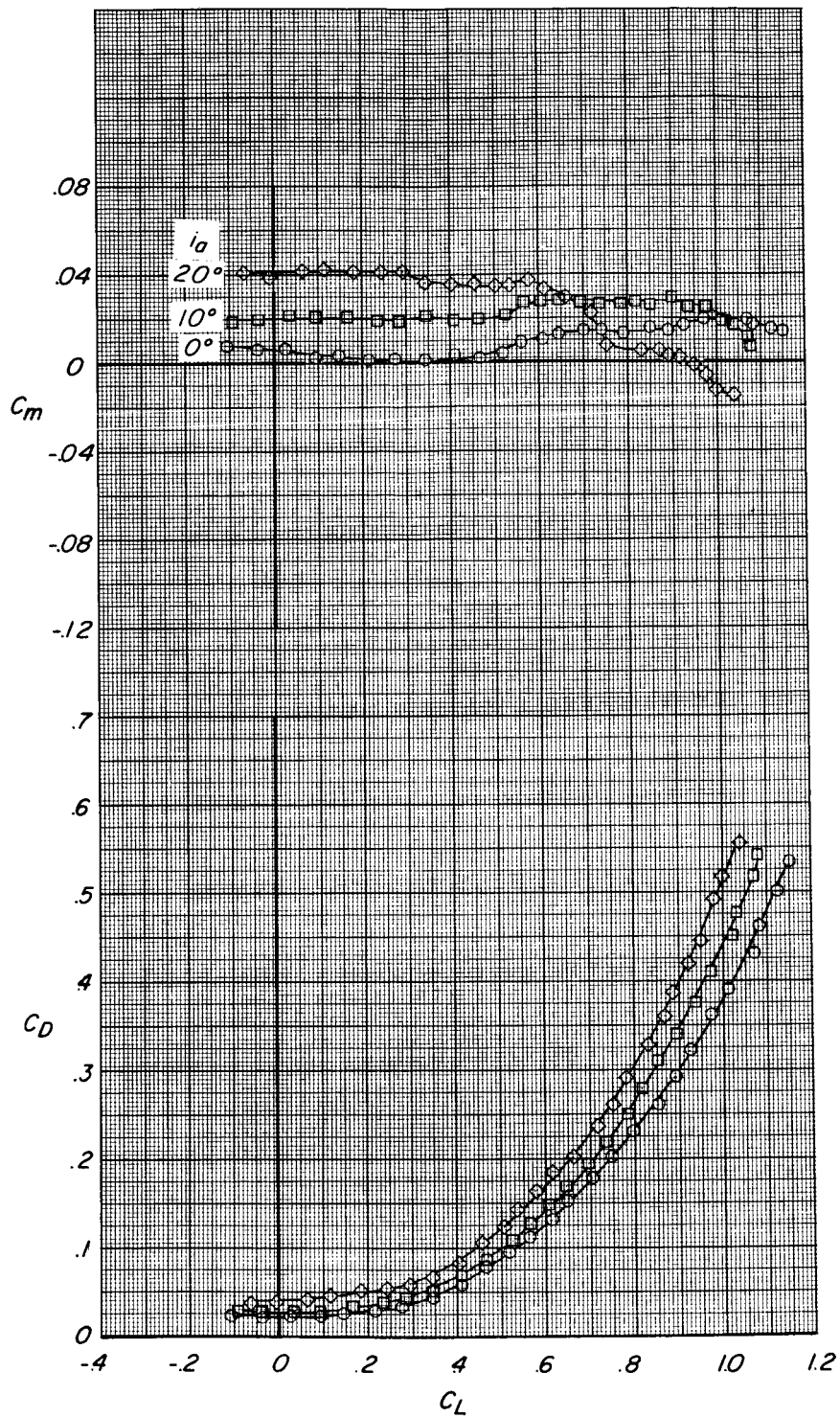


Figure 10.- Concluded.

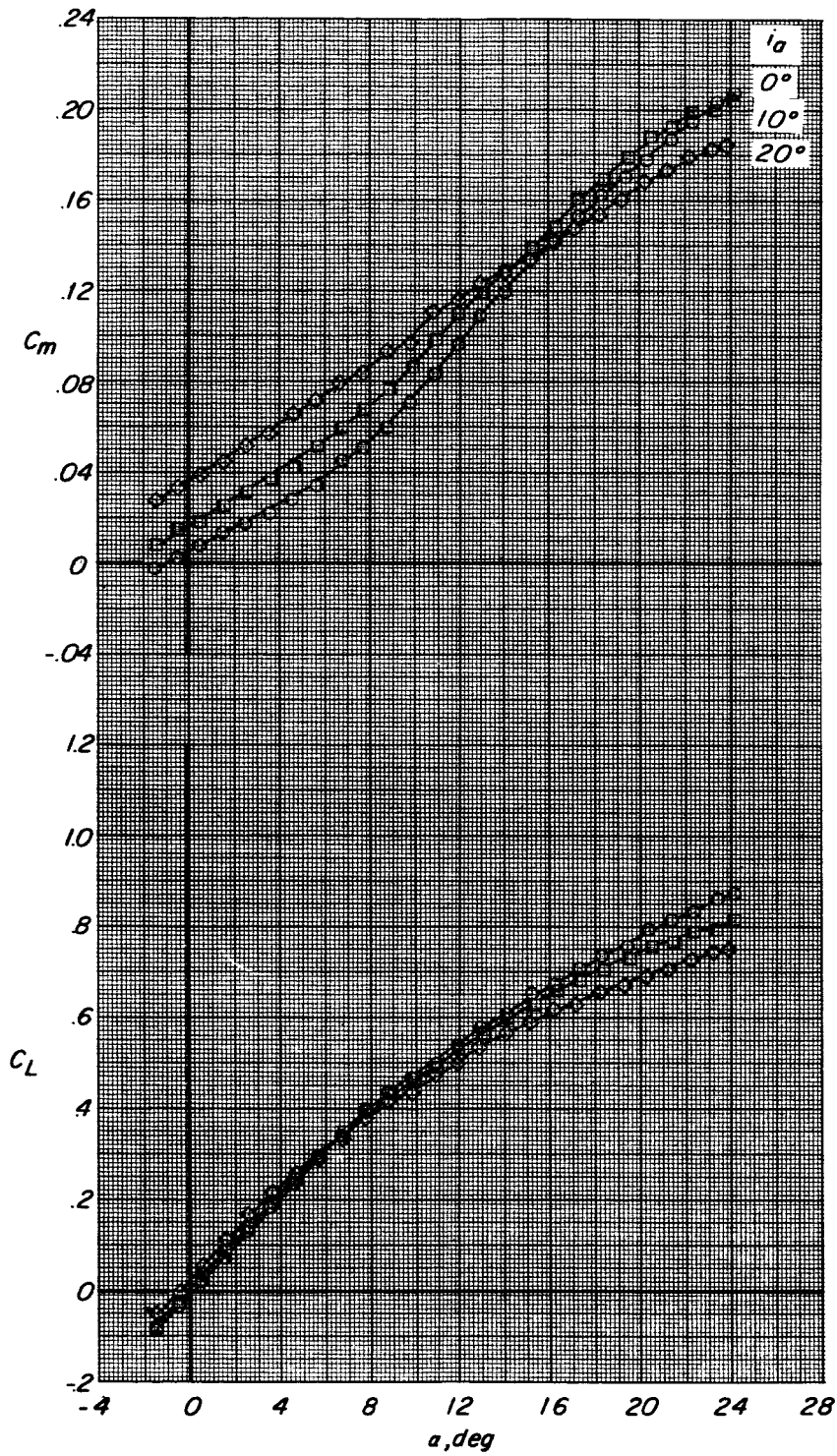


Figure 11.- Effect of positive wing-apex incidence angle on aerodynamic characteristics of model with fixed wing apex.
Horizontal tail off; $\Lambda = 25^\circ$; $h_s = 0$

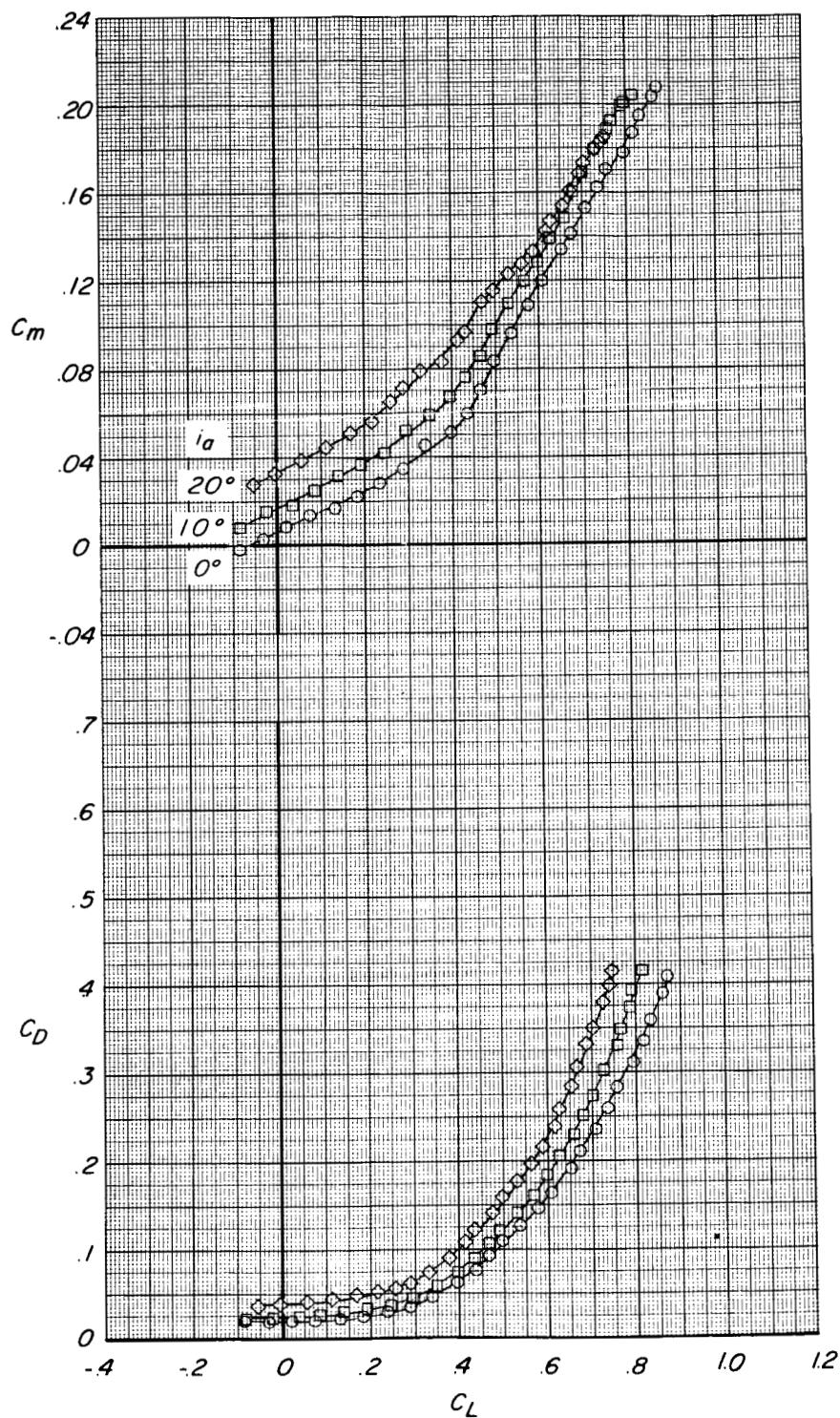


Figure 11.- Concluded.

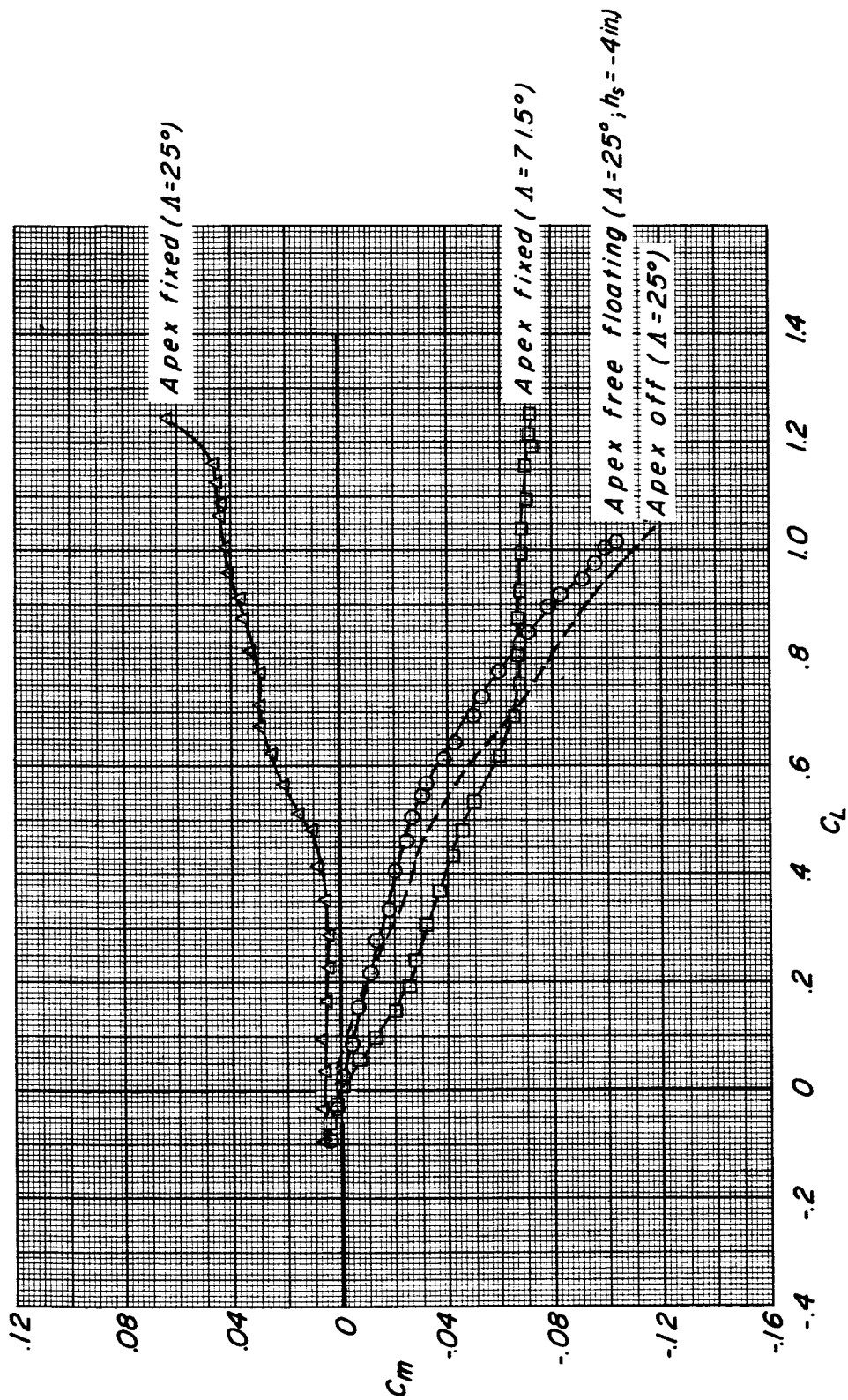


Figure 12.- Comparison of pitching-moment characteristics with free-floating, fixed, and retracted wing apex.
(Data for $\Lambda = 71.5^\circ$ and apex-off configurations from ref. 6.)

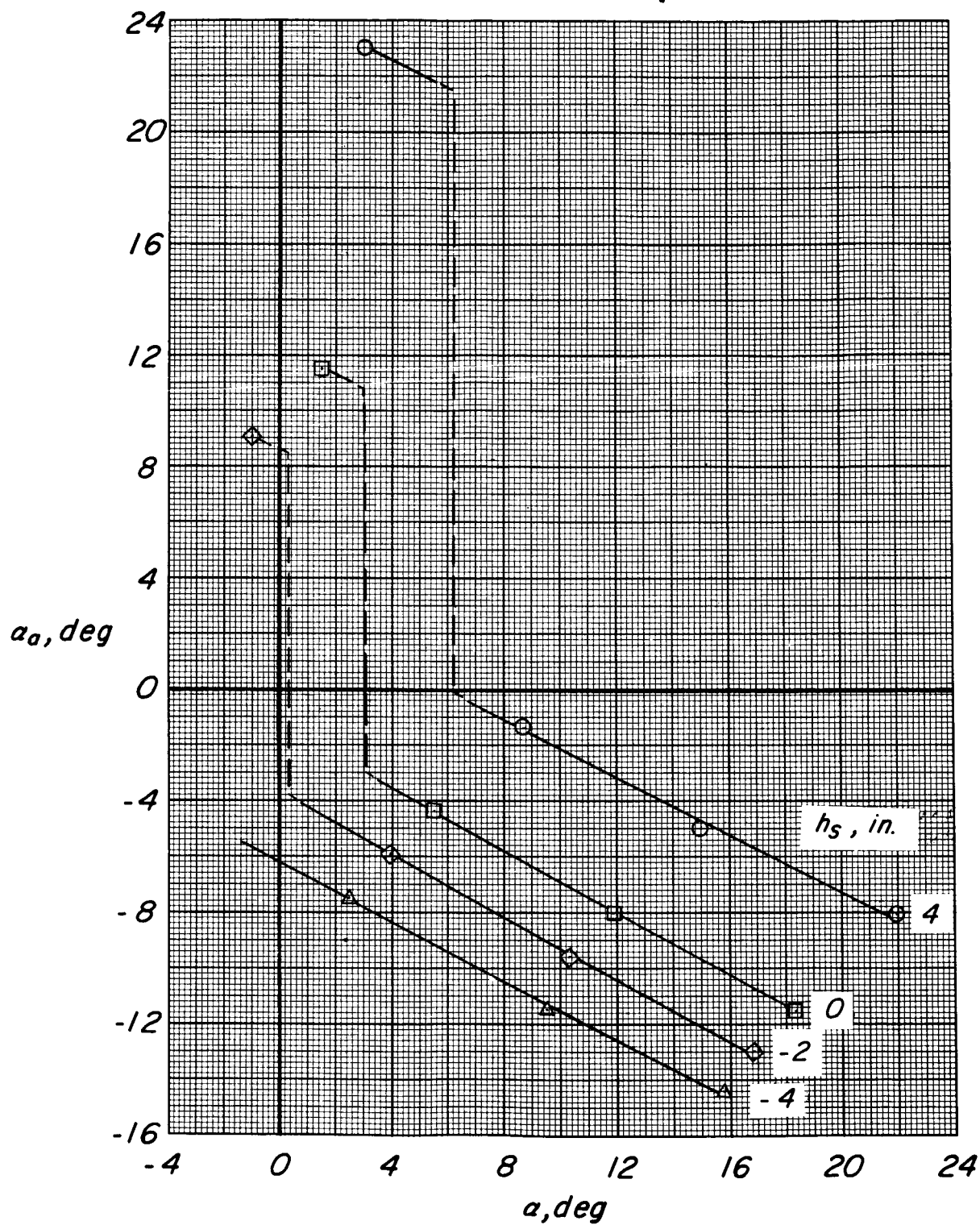


Figure 13.- Effect of angle of attack and apex spoiler deflection on wing-apex floating angles. Complete configuration; $\Lambda = 25^\circ$.

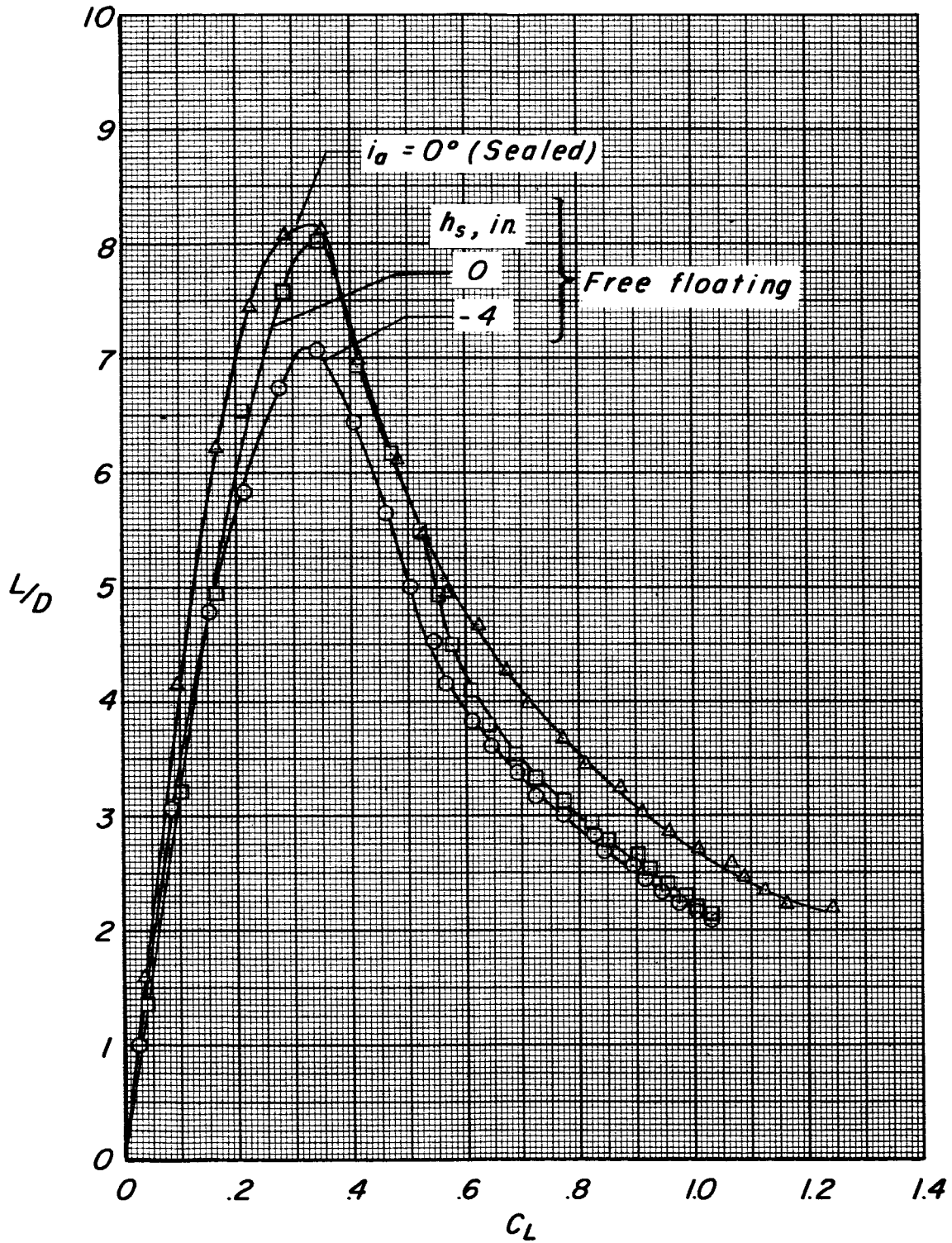


Figure 14.- Effect of free-floating wing apex on variation of lift-drag ratio with lift coefficient. Complete configuration; $\Lambda = 25^\circ$.

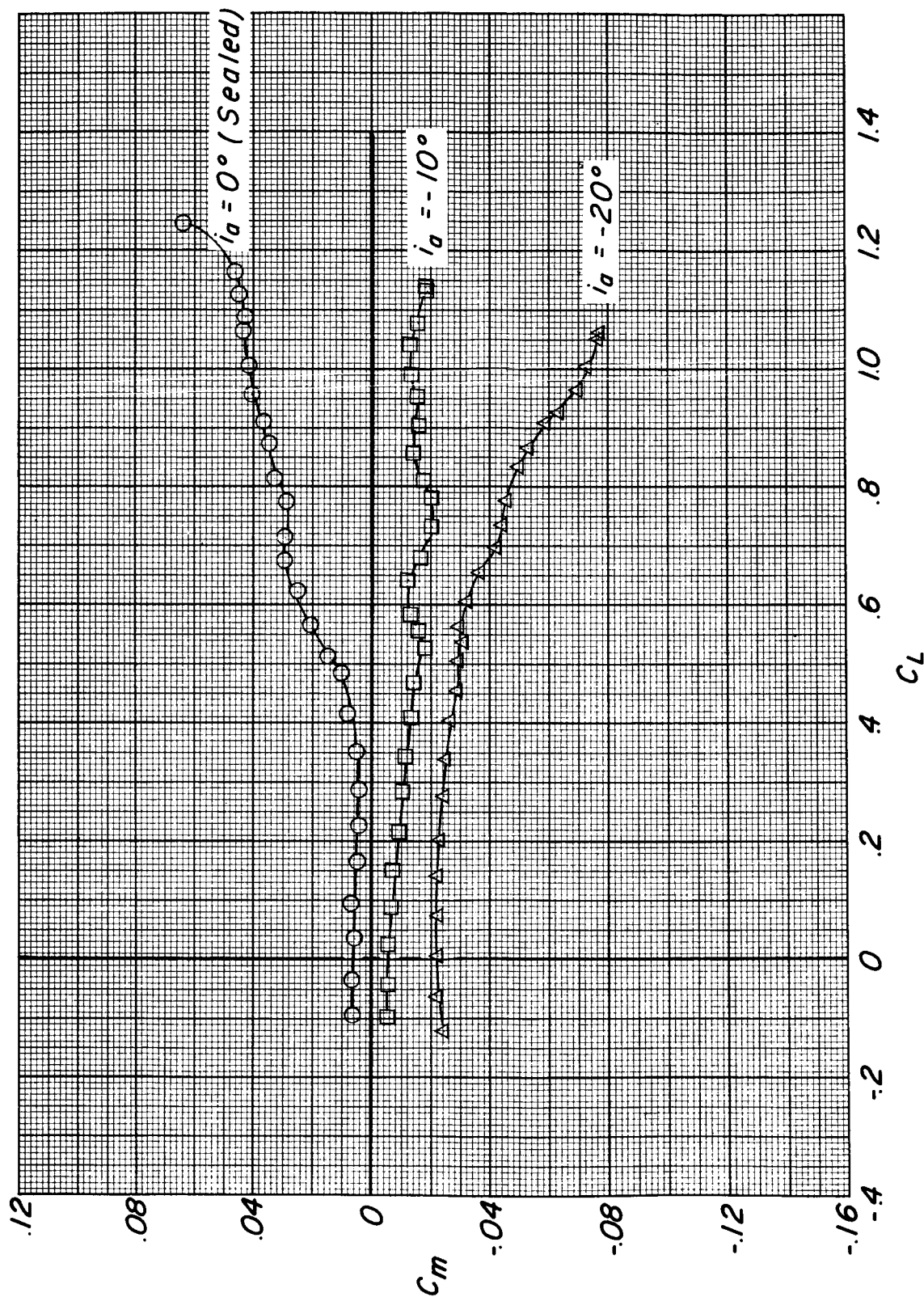


Figure 15.- Effect of wing-apex incidence angle on variation of pitching-moment coefficient with lift coefficient. Complete configuration; $\Lambda = 25^\circ$; $h_s = 0$.

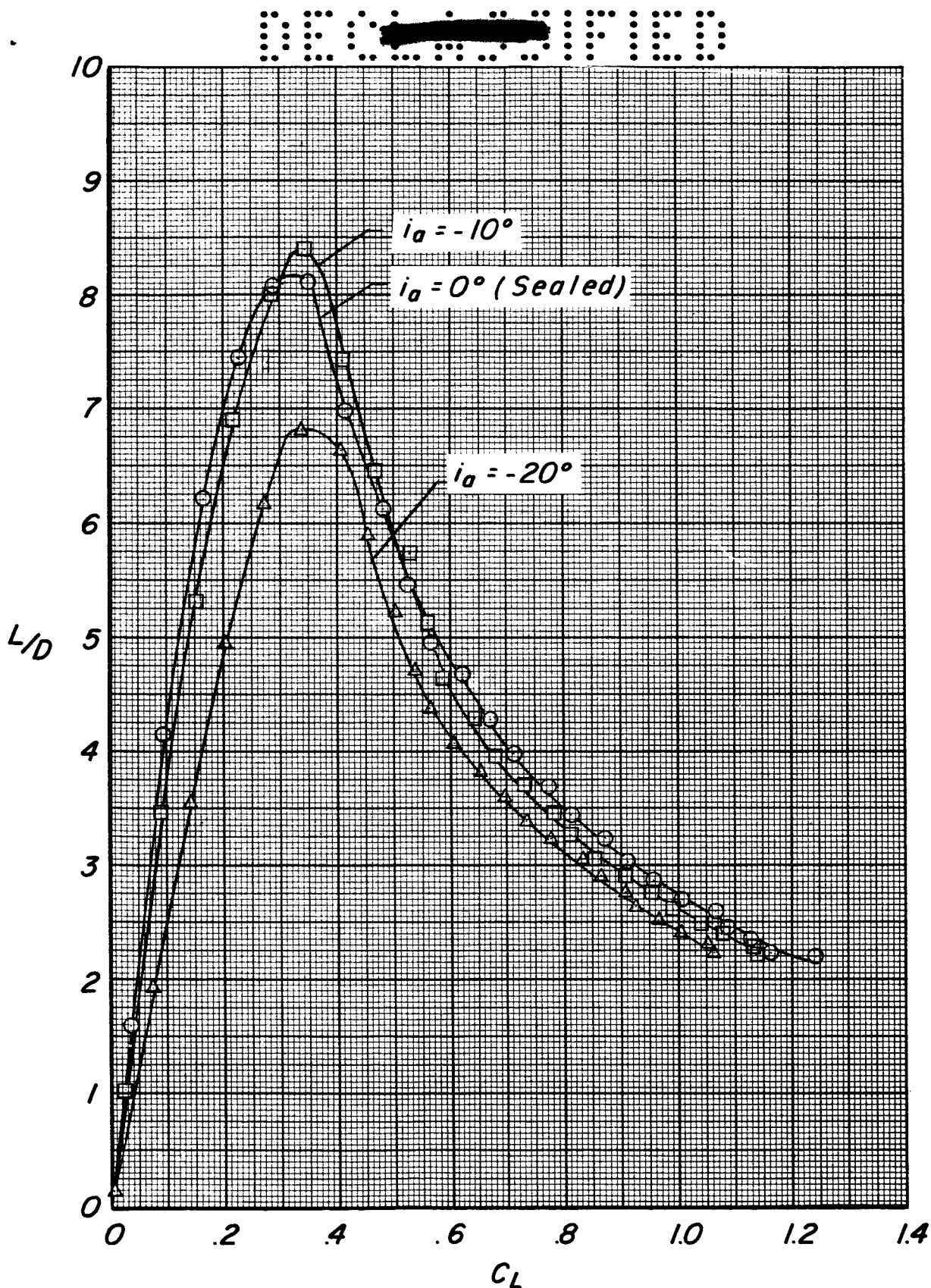


Figure 16.- Effect of wing-apex incidence angle on variation of lift-drag ratio with lift coefficients. Complete configuration; $\Lambda = 25^\circ$; $h_s = 0$.